

A MEASUREMENT SET-UP FOR DETERMINING
ATMOSPHERIC TURBULENCE

I. Schmidt



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16. Abstract Several 80 meter masts were instrumented for wind turbulence measurements at the Meppen firing range. Measurements of wind velocity components, dew point, temperature were performed at heights of 80 m, 48 m, 32 m, 16 m, 8 m, 4 m, 2 m and 1 m above ground. Wind velocity is measured with the Vector Vane device.			
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A MEASUREMENT SET-UP FOR DETERMINING
ATMOSPHERIC TURBULENCE

I. Schmidt *

A measurement installation has been installed on the grounds of the Meppen test facility which is primarily used for determining the size of small scale atmospheric turbulence structures. In contrast to previous measurement installations, these dimensions cannot only be determined as a function of time but also in all three space dimensions. /21**

This measurement installation was built because of the requirement for determining corrections to be made during the firing of unguided artillery rockets in order to take into account the wind structure.

For each type of rocket the so-called wind influence function is of course known. This indicates the angle by which the rocket is deflected from the nominal direction at burnout if a crosswind having unit velocity exists. In this way it is possible to determine the angular error of the rocket at burnout if the crosswind is known along the trajectory. This knowledge is first required up to the point at which burnout occurs along the

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trajectory. After this the rocket behaves like a normal projectile and the influence of the wind on this part of the trajectory can be determined using conventional methods. I will not discuss this.

Therefore, we require wind measurements which must be carried out at as many points as possible of a large number of possible rocket trajectories, so as to be able to give indications on target scatter of rockets. First of all it is unimportant whether one can actually fire rockets along the trajectories. In order to be able to describe the influence of obstacles in the air flow (usually a rocket will be fired from a concealed location), it is first necessary to carry out measurements in an undisturbed terrain so as to be able to separate the effects of obstacles and the effects of the undisturbed flow.

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For this reason we set up two 80 m masts separated by a distance approximately corresponding to the distance of burnout of an artillery rocket. Since the turbulence shortly after launch has the greatest influence, in addition to the main mast A of the installation, we also set up two 48 m masts at distances of 60 and 200 m, respectively, which are in the direction of 210 and 300° respectively, as seen from A. In addition a mobile mast was used in order to study the obstacle effect of Mast C, houses, bushes and similar structures. The Masts A and B were set up over terrain which was as free of obstacles as possible. The Mast C can be connected using a 500 m cable at 7 points of the 3000 m long connection cable between the masts A and B. In this range (Mast B is 2500 m southwest of Mast A), there are a large number of obstacles in the otherwise obstacle-free terrain.

We measured the following elements: the three-dimensional wind vector at the Masts A and B at heights of 80, 48, 32, 16, and 8 meters, at Masts A1 and A2 (the two 48 meter high auxiliary masts at A) at heights of 48, 32, 16 and 8 meters, and on Mast C at heights of 32, 16 and 8 meters. However, we were only able to make simultaneous measurements at 13 points. We also measured the horizontal wind velocity as an average over 10 minutes at the Masts A and B at heights of 80, 64, 32, 16, 8, 4, 2 and 1 meter, the wind direction at Mast A at a height of 16 meters averaged over 10 minutes. At Masts A and B, we measured the temperatures and dew point temperatures at a height of two meters averaged over 10 minutes. At A and B we measured the temperature differences between the temperatures at 16 and 2 meters, 48 and 16 meters, 80 and 48 meters as well as the dew point differences between 80 and 2 meters, all averaged over 10 minutes. We partially measured the horizontal wind velocities averaged over 10 minutes at heights of 32, 24, 16, 12, 8 and 4 meters above the ground at Mast C.

It may seem remarkable that the wind direction was only measured once. This is because under normal weather conditions, the vertical rotation of the wind direction is about 2° at a height of 80 meters and is therefore much smaller than the measurement errors in the wind direction which are about 5° . In addition the wind directions established during turbulence measurements are average values of the three-dimensional wind vectors.

All of the wind measurement devices above a height of two meters are mounted on booms which are 5 m long on the stationary towers. Since these masts are lattice structures with triangular cross sections and with a side length of 1.8 m, the disturbances to the wind measurements produced by the mast amount to only a

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few percent and are therefore small as long as the mast is not covered or if the wind passes through the mast on its way to the measurement instruments. On the moveable mast, the ratios of the boom lengths and mast dimensions are the same as for the fixed mast. All of the fixed masts have moveable members.

Following is a description of the individual measurement transducers:

The emphasis of the measurements was to determine the small scale turbulence in order to establish a launching ramp correction for undeflected artillery rockets. For this purpose it is permissible to restrict oneself to gust wavelengths of at least the length of such a rocket. Wavelengths shorter than a few meters are therefore of no interest. Therefore, we can use mechanically sensitive wind vanes. For this installation we selected the so-called Vector Vane, which was on the market at the time the installation was planned. It is made in the United States by the firm Meteorology Research, Inc. and has proven itself well. However, it is not a device for continuous use. Therefore, they were only installed during measurement series carried on over a few weeks, which was done several times a year.

The Vector Vane has a distance constant (the wind path after which the wind vane has turned into the changed wind up to 63%) of about one meter. This means that it can still resolve wind wavelengths of two meters. The wind velocity is recorded as a propeller rotation. A slot diaphragm is connected with the propeller which interrupts a light beam. The interruptions are recorded by a photocell and a pulse sequence is produced. Twenty pulses correspond to a wind path of 90 cm.

The wind direction and inclination are obtained by potentiometers which indicate the position of the longitudinal axis of the wind vein. The axis is always turned downstream by means of four tail fins. This means that these two variables are available as a direct voltage. They are converted to digital form at the base of the tower by converting the voltages to frequencies. Then the frequency pulses are counted. In this way, one obtains true averages for the selectable time intervals of 0.25, 0.5, 1 or 2 seconds. By selecting the time intervals, the time separation of a measurement is also established at the same time.

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The velocities are already available as pulsed sequences. Therefore, we simply add up the pulses which occur during the averaging period.

The measured values are summarized in pulse telegrams and are transmitted by four transmitters over wires to a time multiplex pulse code transmission system located 20 km away at the test facility center Meppen. A maximum of 13 wind vanes can carry out measurements at the same time. This means that up to $13 \times 4 \times 3 = 156$ measured values per second must be transmitted and stored. Magnetic tape storage is appropriate for doing this.

The accuracy of the Vector Vane is as follows:

Response sensitivity, 0.25 m/sec for all three components. The deviation from linearity is less than 1% of the measured range. The quantization error after digitalization is $0.9 \text{ m}/20 = 0.045 \text{ m}$ for the wind path, 0.5° for the inclination and 1° for the direction.

During the operations it was found that the uncertainty in the inclination and directional devices was a few degrees. This is not very disturbing for the inclination because under conditions of an open terrain we can use the hypothesis of a vanishing average vertical component of wind. However, this must be considered for the direction, because the indicated measurement errors of the wind veins are affected. The velocity averages are less than those from the Lambrecht contact anemometers by 0.2 to 0.3 m/sec. installed at the same height. Since these devices because of their increased inertia follow a wind increase faster than a wind decrease, the difference occurs in the direction required by the theory. It can be expected that the velocity values of the Vector Vanes are accurate to about 0.1 m/sec on the average.

Too much effort is required to operate continuously with the vector vanes. Therefore, elements which require less effort such as the horizontal wind velocity, wind direction, temperature and dew point temperature, were continuously recorded as averages over 10 minutes. Since the vertical profiles of the wind and the temperature are closely coupled with the turbulence conditions, it can be expected that frequencies of turbulence conditions can be established from a climate representation of these elements.

The characteristics of the measurement transducers used for this are as follows: / 25

Errors in wind direction measured with a Lambrecht wind vane can reach $\pm 5^\circ$. The wind vane is connected with a wake device through a rotational field transducer which contains two potentiometers whose jump points are separated by 180° . Their two wind directions are continuously printed out. If a potentiometer runs through its jump point, then the No. 445 is

printed out as the 10-minute average. Under normal conditions, this indication occurs when the wind comes from the East. This means that one can unambiguously recognize rotating winds as well as the flow of the wind direction vane through the tower, which can be eliminated from the evaluation.

The horizontal wind velocity is measured using Lambrecht contact anemometers. Their contact separation is selected such that when averaging is carried out over 10 minutes, the display is in tenths of knots. The measurement accuracy is given as $\pm 2\%$.

The temperatures and the vertical temperature differences are measured by means of two platinum 100 ohm resistance thermometers in hard glass, protected against radiation and ventilated according to Frankenberger. The two thermometers are located in the two branches of a Wheatstone Bridge which is supplied by direct current. In practice, the deviation of the thermometer resistance from 100 ohms is measured. The measurement error is equal to the calibration error of about ± 0.1 Celsius. The display accuracy at any temperature is equal to the display unit of 0.5° Celsius. In the case of the vertical temperature differences, the two readings are given to within 0.05 degrees Celsius.

The dew point temperature is measured using lithium chloride transducers. Lithium chloride is greatly hygroscopic and must therefore be heated if the vapor pressure at its surface is to be equal to the vapor pressure of the atmosphere. This temperature, also called the conversion temperature, because lithium chloride is transformed at this temperature from the solid state to the liquid state or at least from an electrically poorly conducting medium into a highly conducting medium, is therefore a measure for the water vapor pressure in the atmosphere, that is, the dew point temperature. In the measurement installation, a

suitable bridge circuit converts it to the dew point temperature.

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All these variables are produced in the form of direct voltages and are converted into a pulse sequence by means of a voltage-frequency conversion unit. During the averaging period of ten minutes, the pulses are summed and then they are relayed to the central point in conjunction with the turbulence measurements. There they are printed out on a remote typewriter and at the same time a punched tape is produced which is available for evaluation by electronic computers.]

It should be realized that all of the printed measured values are not calibrated and may need correction. Since the transmission unit is 0.5°C for the temperature and dew point, any measured temperature values between 8.5 and 8.99°C results in the display 085.]. Accordingly the indicated vertical temperature and dew point differences should be interpreted using the transmission unit of 0.05°C .

We must now describe the storage and data preparation for the turbulence measurements at the central point, since up to the present we have only talked about the measurement data acquisition. At the central point the pulse telegrams are stored on a magnetic tape. This tape has five tracks, one for each of the four transmitters which are transmitting the measured data and a time track which contains minute pulses and a 1200 Hz tone. A high degree of writing and reading reliability is obtained by frequency modulation. Measurement sequences] having durations up to $3\frac{1}{4}$ hours can be stored on a magnetic tape independent of the selection of integration time and number of simultaneously used Vector Vanes. The tape recorder Ampex FR 1300 is used for this. The magnetic tapes written in this way are then called analog tapes in the following. Even though data storage is already digital, it is still not suited for the

the computer.

This is why each of the four data tracks must be rewritten on to a second magnetic tape unit Ampex TM 7. This unit writes the measurement data together with a few characteristic values set at the console for identifying the measurement series. This is done so that the tapes can be read by the magnetic tape units IBM 729/IV. The information density is 556 bit per inch, and the recording mode is binary. Three hundred thousand measurements of a maximum of four Vector Vanes can be stored on one digital tape, which is the name given to these magnetic tapes in the following. /27

The basic recording unit consists of a cycle which includes four simultaneous recordings from the four wind vanes connected to one data track. The fifth and last word of the cycle contains the characteristic values and two quantities used to assign a time to the measured Vector Vane values.

The number of cycles can be selected at the console (12 as a rule). These are summarized into a block as a basic recording unit and these are summarized on the digital tape and stored. The information from each block is checked in the usual manner for digital magnetic tapes. This means that the recorded writing and reading errors will be noticed with a high degree of certainty.

An arbitrary number of such blocks after one another result in a measurement sequence, the end of which is recorded on the tape by means of an "end of file" sign. It is possible to store an arbitrary number of such measurement sequences after one another on the tape. These magnetic tapes constitute the final product of the measurement installation as far as the storage of

the turbulence measurements is concerned. Since they cannot be processed at the Meppen test facility, the evaluation is being done by the Meteorological Institute of the TH Darmstadt. The digital tape first goes to the German Computer Center at the Darmstadt and they are processed using the IBM 7094 computer. Using this computer the characteristic values and information for time tagging contained in the data works are separated out and prepared. They are then output together with the wind vane measurements on to magnetic tape. This tape can then again be processed further by the IBM 7040 of the TH Darmstadt. At the same time air frequencies and disturbance frequencies as well as average values and scatter values of the wind components are calculated for each Vector Vane and printed out. Using this information one can decide whether a further evaluation of this measurement series is justified. If this is the case, then the calibration correction is applied to the wind velocities and the Cartesian components of the wind vector with respect to a coordinate system oriented according to the average wind vector of the corresponding measurement series are determined from the wind vector components direction, inclination and velocity. All of the wind components are again written onto magnetic tape in this form. Thus, they are available for special evaluations. Of course they are primarily used for determining spatial correlations of the wind components as well as for determining spectral density functions, as well as many other purposes.

The distribution of wind measurements for strong vertical mixing will be discussed as an example. We noticed three things:

- There was no wind rotation with altitude,
- The scatter of the vertical component of the wind increases considerably with altitude but is always smaller than the horizontal components,

- The longitudinal and lateral scatter are almost independent of the altitude above ground,

- These findings agree qualitatively with the theoretical expectations.

Wind rotations with altitude were only demonstrated with certainty when there were temperature increases with the altitude. Of course, this is only true for the lowest 80 meters above the ground.

Even a casual review of the continuously recorded vertical profiles of wind velocity and temperature show the following:

- On clear nights the minimum temperature at Mast B is usually one to 2 degrees C lower than at Mast A. The reason for this is probably the difference in the nature of the ground, because at B we have a marsh which has poor conductivity under dry conditions. On the other hand, there is sandy ground under Mast A,

- The 10-minute averages of wind velocity showed differences up to a height of 80 meters which can amount to 10% of the average value from both towers, even for uniform horizontal weather conditions. These differences seem to depend on the wind direction in a systematic way and must therefore be attributed to the influences of growth and ground. These influences are different in the region of influence for the wind in the windward side of the two towers.

This discussion has shown that a number of questions can be answered by using this installation and its measured data. It would take us too far field within the framework of this paper to describe all the possible problems.

A brief description of the measurement installation was given by LEBUS in the scientific reports of the Geophysical Consultation Service of the German Army in 1970.

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